EFFECT OF PLY-ANGLE IN FLEXURAL STRENGTHENING OF STEEL ANGLE SECTIONS USING CFRP

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Abstract
Use of CFRP in structural strengthening is very common nowadays. It is being effectively utilized in many sectors especially the concrete industry for the purpose of retrofitting as well as rehabilitation. Many studies are progressing to prove its efficiency in the steel sector. The purpose of this paper is to investigate the effect of ply-angle of CFRP layers in improving the flexural strength of steel angle sections used in towers and beams. The specimens are modelled and analysed using ANSYS 15.0 software. A series of ply-angles (0°, ±15°, ±30°, ±45°, ±60°, ±75°, 90°) and their combinations have been selected for the study. Results show that variation of ply-angle influences strength as well as the overall deformation of the section.
Keywords: Steel Equal Angle, Slenderness ratio (b/t), CFRP, Ply- angle, ANSYS 15.0

I. INTRODUCTION

In this competitive world, we see the rise of tall structures being built to satisfy human needs. They could be of tall concrete or steel structures or a combination of both. One necessity that arises along with the completion of the structure is to maintain the same for more than its design life due socioeconomic reasons. Transmission towers fall into this category as they are tall steel structures and they accommodate large area which is otherwise difficult to find. So it is not practical to build another tower rather it would be better to upgrade/maintain the existing ones by adopting suitable techniques in order to utilise their efficiency to the maximum.

Transmission towers comprise mainly of steel angle sections which commonly behave as truss members subjected to axial tension or compression. But it is found that the connection configuration at the ends of the truss members are not truly pin jointed. The angles are usually coped to avoid interference with the adjoining members and are connected to one leg of the member, resulting in eccentric loading. This leads to secondary bending stresses that may become significant in certain loading conditions [4]. Hence there arises a need for strengthening the same against flexure.

Use of CFRP (Carbon Fibre Reinforced Polymer) for retrofitting and rehabilitation has already gained popularity in the concrete industry and at present many experiments are also being conducted to study its efficiency in the Steel sector.

II. SOFTWARE USED – ANSYS 15.0

ANSYS is a Finite-Element (FE) package used widely in industry to simulate the response of a physical system to structural loading, thermal and electromagnetic effects. ANSYS uses Finite Element Modelling (FEM) to solve underlying governing equations and the associated problemspecific boundary conditions [5]. ANSYS Workbench 15.0 interface has been used for the present study.

III. METHODOLOGY

Structural steel equal angle sections available in SP 6-1 (1964) [6] were selected for the study. The sections were classified based on Clause 3.7 of IS 800 (2007) [7] as shown in Table 1, of which Semi-Compact and Slender sections were chosen for the present study.

TABLE I

SECTION CLASSIFICATION

Sl.No.	Section	Ratio	Limits
1.	Plastic	b/t*	<9.4ε*
2.	Compact	b/t	>9.4ε but <10.5ε
3.	Semi-Compact	b/t	>10.5ε but <15.7ε
4.	Slender	b/t	>15.7ε

*Yield stress ratio, $\varepsilon = (250/f_y)^{(1/2)}$, f_y =250MPa

*b= specimen width, t= specimen thickness

Numerical modelling was done using ANSYS Workbench, based on the experimental work of Mahendrakumar Madhavan *et al.* (2015) [4]. In their study, they adopted a new technique of strengthening equal angle sections by converting open section to closed section using suitable internal formwork (cardboard – 600kg/m^3) and further wrapping the same with CFRP. This study focusses on the effect of ply-angle of CFRP in improving strength and its effect on overall deflection.

A. Specimen Layout

The specimens selected from SP 6-1 (1964) are listed in Table 2. The length of the specimen is taken to be 1.4m [4].

TABLE II

SELECTED SECTIONS

Sl.No.	Section (mm)	Nomenclature	Type
1.	65x65x5	A65T5	Semi-Compact
2.	70x70x5	A70T5	Semi-Compact
3.	75x75x5	A75T5	Semi-Compact
4.	90x90x8	A90T8	Semi-Compact
5.	100x100x6	A100T6	Slender
6.	130x130x8	A130T8	Slender
7.	200x200x12	A200T12	Slender

Epoxy Carbon – 230GPa – Woven – Prepreg available in ANSYS Engineering Data Resources, is chosen for modelling CFRP. The thickness of CFRP is taken to be 0.25mm for a single layer. Fibre orientations were selected at random based on previous studies [1], [2], [3] and [4]. The selected fibre orientations are listed in Table 3.

TABLE III

SELECTED FIBRE ORIENTATIONS

Sl.No.	Orientation(°)	No. of Layers	Thickness (mm)
1.	[0]	1	0.25
2.	[0/0]	2	0.5
3.	[0/90]	2	0.5
4.	[15]	1	0.25
5.	[15/-15]	2	0.5
6.	[30]	1	0.25
7.	[30/-30]	2	0.5
8.	[45]	1	0.25
9.	[45/-45]	2	0.5
10.	[60]	1	0.25
11.	[60/-60]	2	0.5
12.	[75]	1	0.25
13.	[75/-75]	2	0.5
14.	[90]	1	0.25
15.	[90/90]	2	0.5

The labelling of specimens is shown in Table 4.

TABLE IV

LABELLING OF SPECIMENS

Sl.No.	Specification	Nomenclature	Thickness of CFRP(mm)
1.	Control Specimen	CS	
2.	Skin-Strengthened	CR	0.25
3.	1-layer wrap	C1	0.25
4.	2-layer wrap	C2	0.5

B. Loading and Boundary Conditions

A 4-point Displacement-controlled loading was applied in order to simulate the flexural behaviour of the specimen. 100mm wide steel plates were provided on either ends in order to facilitate connections.

Modelling of specimens was done in Static Structural analysis system whereas modelling of Ply was done by linking Static Structural to ACP Pre/Post component system.

The modelled specimens and their loading are shown in Fig.1-4.

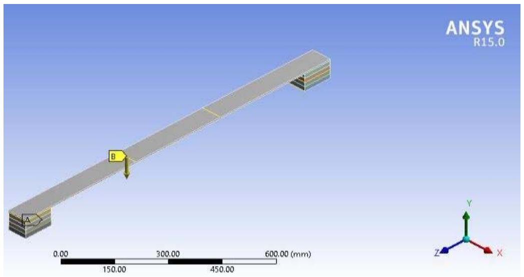

Fig. 1: Control-CS Specimen

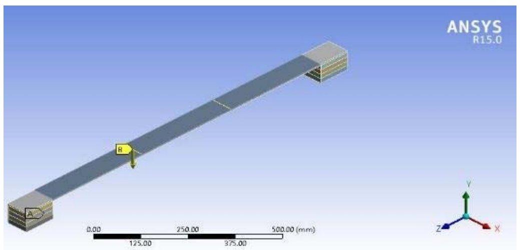

Fig. 2: Skin-Strengthened-CR Specimen

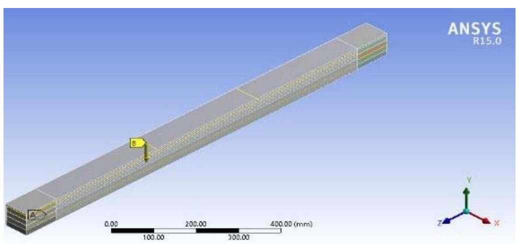

Fig. 3: C1 Specimen

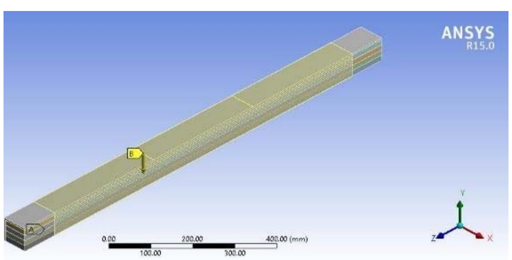

Fig. 4: C2 Specimen

IV. RESULTS AND DISCUSSION

The results obtained are summarised in Table 5. Results on average show that for skin-strengthened specimens, maximum strength was obtained for [0o] and [90o] configuration in case of Semi-Compact sections and [90o] configuration for Slender sections. Similarly, maximum strength for 1-layer wrap was achieved for [90o] configuration in case of Semi-Compact sections and [0o] and [90o] configuration for Slender sections. For 2-layer wrap maximum strength was achieved for different configurations for both Semi-Compact sections and Slender sections. Also overall deflection was maximum for different configuration in both cases. This shows that variation of ply angle influences the entire flexural behaviour and also helps to improve the overall capacity of specimens. The deformed shape of specimens of A65T5 are shown in Fig. 5-8.

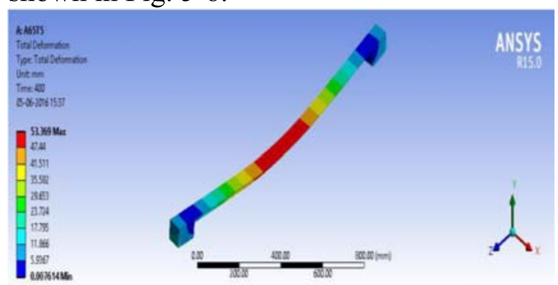

Fig. 5: Deformation of CS Specimen

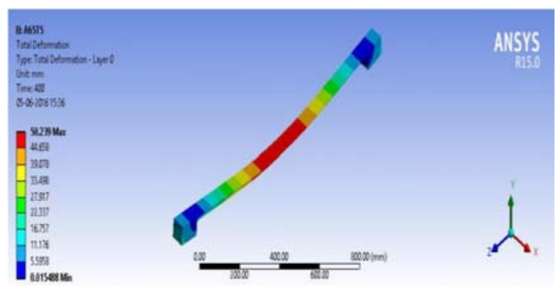

Fig. 6: Deformation of CR (0O) Specimen

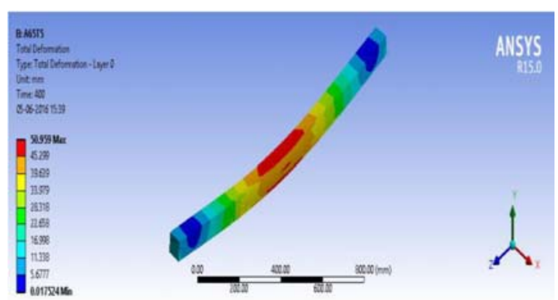

Fig. 7: Deformation of C1 (0O) Specimen

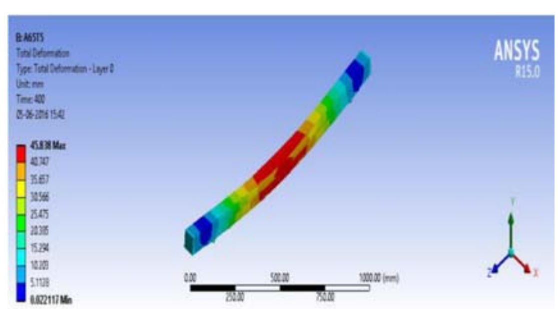

Fig. 8: Deformation of C2 (0 O/90O) Specimen

TABLE V

SUMMARY OF RESULTS

Sl.No.	**Specimen**	**Label**	**Ply Angle Configuration-Giving Maximum Result(°)** Δ	W	**Maximum Overall Deformation, δ (mm)**	**Maximum Load, W (kN)**
1.	A65T5	CS			53.37	10.66
		CR	[45]	[90]	50.65	13.37
		C1	[60]	[90]	51.00	31.41
		C2	[0/0]	[15/-15]	46.50	75.61
2.	A70T5	CS			53.58	12.80
		CR	[45]	[0]	51.83	24.56
		C1	[15]	[90]	52.11	36.51
		C2	[60/-60]	[0/0]	49.39	97.12
3.	A75T5	CS			53.16	14.61
		CR	[90]	[0]	52.79	15.38
		C1	[90]	[30]	52.35	58.48
		C2	[0/90]	[90/90]	50.86	88.67
4.	A90T8	CS			53.40	32.91
		CR	[60]	[90]	51.42	39.85
		C1	[45]	[0]	48.52	84.15
		C2	[45/-45]	[0/90]	47.94	131.12
5.	A100T6	CS			53.30	31.56
		CR	[60]	[90]	50.07	40.36
		C1	[90]	[90]	71.11	90.52
		C2	[0/90]	[0/0]	51.21	187.10
6.	A130T8	CS			53.51	72.59
		CR	[45]	[90]	51.03	87.73
		C1	[0]	[0]	108.54	189.79
		C2	[45/-45]	[90/90]	47.74	423.78
7.	A200T12	CS			54.46	272.05
		CR	[45]	[90]	51.57	310.36
		C1	[90]	[90]	152.37	533.05
		C2	[45/-45]	[15/-15]	41.37	966.96

IV. CONCLUSION

In this study the effects of variation of ply-angle was considered. The results show that variation of ply-angle configuration of CFRP influences the flexural strength of specimens and also affects the overall deformation for both Semi-Compact and Slender sections. Also, at particular configurations tremendous increase of strength was observed. This shows that use of CFRP helps to improve flexural strength of steel angle sections as in case of concrete sections and hence its use as a strengthening material in steel industry need to be encouraged.

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